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6. AUTHOR(S)
W. C. Torrez, and W. J. Yssel

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Space and Naval Warfare Systems Center
San Diego, CA 92152–5001

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In this paper, we consider the case of two over-the-horizon radars. The main algorithm is designed to hand-off range bias errors from one radar's ionospheric mode to a second radar. It is expected that the resultant algorithmic development based on the work described in this paper will improve track positional accuracy by more than 50%.

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OVER-THE-HORIZON RADAR SURVEILLANCE SENSOR FUSION FOR ENHANCED COORDINATE REGISTRATION

William C. Torrez and William J. Yssel

SPACE AND NAVAL WARFARE SYSTEMS CENTER, CODE D7212
San Diego, California 92152-5302
torrez@spawar.navy.mil, yssel@spawar.navy.mil

ABSTRACT

Redundant data from independent over-the-horizon radar systems can increase track accuracy by providing more independent "looks" at the target. With proper geometry, complementary radar systems can aid in resolving uncertainties in the coordinate registration through the various ionospheric modes. Systematic positional differences between tracks from the separate radars can be used to improve the estimation of ionospheric heights. In operational systems, targets are tracked by multiple over-the-horizon radars in overlapping coverage areas. In this paper, we consider the case of two over-the-horizon radars. The main algorithm is designed to hand-off range bias errors from one radar's ionospheric mode to a second radar. It is expected that the resultant algorithmic development based on the work described in this paper will improve track positional accuracy by more than 50%.

1. INTRODUCTION

Coordinate registration (CR) for high frequency (HF) over-the-horizon radar (OTHR) is done by ray tracing through ionospheric models which are estimated using real-time sounding observations of the ionospheric state. In order to track the state of this very dynamic medium, the sounding and modeling processes are repeated every twelve minutes. This often introduces uncertainty in coordinate registration, because of the inherent variability in the ionosphere and its models. Thus biases, as introduced by estimates of the ionosphere (causing uncertainties in coordinate registration), ultimately result in systematic errors in the ground positions of targets as measured by miss distances. Miss distance is defined as the distance between the radar track position estimate and the truth data position at the same instant of time. OTHR system users [1] have identified improved track accuracy as their current number one operational requirement. Current technologies such as real-time ray tracing, both manual and semi-automatic have recently been introduced [2-4]. A two-dimensional manual real-time ray-tracing algorithm as described in [2] is currently undergoing system implementation and preliminary results have shown miss distance reduction by 50%. It is expected that the resultant algorithmic development based on the work described in this paper will improve track positional accuracy by an additional 50%. Australian researchers [5-7] have been very active in the investigation of improved CR for OTHR track fusion with multisensor multisource target tracks including microwave radar networks and land-based and airborne beacon transponders. In references [8-9], we have also investigated the fusion of OTHR tracks with microwave radar tracks using commercial off-the-shelf algorithms and have suggested an application to enhanced CR. Developments are currently underway to reference target tracks to beacon transponders [10], and in conjunction with real-time ray tracing, these methods are expected to reduce target positional errors in areas in the vicinity of the beacon transponder locations. But many of the areas of interest for OTHR surveillance are

not convenient to operational transponders or ground-based radars, but can be covered by multiple OTHR systems. It is in these areas that this approach promises to have applicability.

2. ANALYSIS APPROACH

Redundant data from independent sensor systems can increase track accuracy by providing more independent "looks" at the target. With proper geometry, complementary sensor systems can aid in resolving uncertainties in the coordinate registration through the various ionospheric modes. Systematic positional differences between tracks from the separate radars can be used to improve the estimation of ionospheric heights. In operational systems, targets are tracked by multiple OTHR systems in overlapping coverage areas. In this paper, we will consider the case of two overlapping OTH radars. In the process of fusing OTH radar tracks into a common ground target track several processes must be accomplished:

Stage one. *Track Association*. From the collection of OTH radar tracks, identify those tracks that belong to or originate from the same physical unit. These can be tracks from the same region but arriving via different ionospheric modes, or from adjacent or overlapping regions that may be operating on a different frequency and therefore having differing paths through the ionosphere, or they may be from an independent OTH radar sharing a common coverage area in which the target resides.
Stage two. *Mode Assignment*. Using the current ionospheric models, find the set of mode assignments that provides the best clustering of transformed positions for each of the identified radar tracks, and assign those tracks to the appropriate mode.

Stage three. *Ground Position Determination*. With the modes determined, each radar track is transformed to ground coordinates and a weighted average is calculated to estimate the position in ground coordinates.

Now if an ensemble of targets is in the coverage area, a systematic error in the ionospheric parameters will manifest itself in each of the tracks, and a correction of this error would improve the accuracy of all target positions in the region. This approach presumes correct or at least consistent mode assignments.

3. RESULTS AND DISCUSSION

A data set was generated using two independent OTH radar systems covering a common surveillance region at about 1500 nmi from both OTH sites. Truth data in the region was provided by a ground-based microwave radar system. During the two-hour data collection period, eleven ground targets were concurrently held by both OTHR systems and by the ground-based microwave radar. The OTHR systems were run in their standard manner, detected the targets, formed tracks in radar coordinates, identified tracks belonging to the same target, selected and assigned ionospheric modes to be used, brought each of the radar tracks to ground coordinates using the appropriate coordinate registration tables, and fused the collection into a common target state. This was done each minute in which the OTHR system held contact on the target. Using the microwave radar to provide the truth target tracks, the F2L-F2L mode was chosen, and the range and cross-range errors for each of the targets were calculated for each minute. The range errors and cross-range errors were plotted in arbitrary units as a function of time, and are shown as figures 1 and 2.

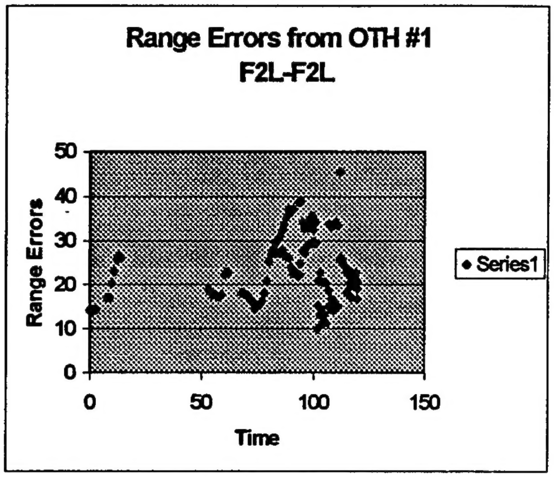

Figure 1. Range errors from OTH radar 1 assuming F2L-F2L mode assignments.

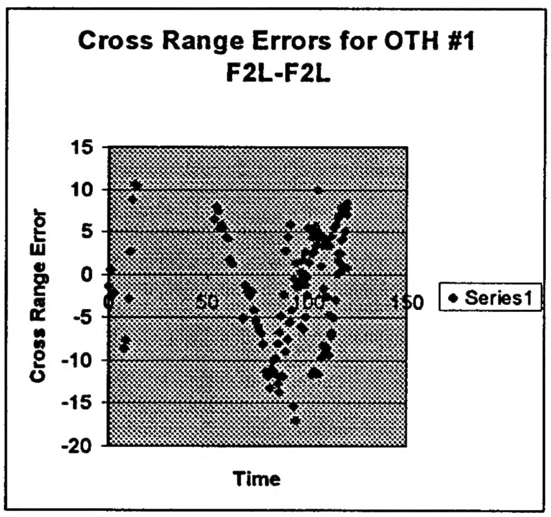

Figure 2. Cross-range errors from OTH radar 1 assuming F2L-F2L mode assignments.

From figure 1, it can be seen that a significant bias was present and persisted over time. The OTHR tracks from the F2L mode appeared to be long in range by 20 to 25 units over the data collection period. There was also a random, somewhat oscillating component to the error. This component most likely results from ionospheric movements or traveling ionospheric disturbances. But it appears to be separable from the modeling bias, which appears to vary much more slowly. Changes to the coordinate registration tables as a result of operating frequency changes or updates from the soundings can be observed as breaks in the data. These can be seen at 60-65 minutes and again at 100 minutes and 112 minutes in figure 1. In figure 2, the cross-range errors show similar ionospheric movement, but since these values are the result of beamforming, the error distribution has nearly zero mean, with very little, if any, bias error. The same phenomena is present in the data from the second OTH radar, that is, a strong bias in the range error distribution and a near zero mean in the distribution of the cross-range errors was observed.

4. CONCLUSIONS

The main algorithm to be developed is designed to hand-off a range correction to OTH radar 1 based on the observation of the cross-range positions observed by OTH radar 2. Likewise, OTH radar 1 will provide its cross-range bearings on common targets by mode for correction of any range bias experienced by OTH radar 2. If this is done for the ensemble of targets in the surveillance region and these results are used to update the coordinate registration tables, targets being detected by only one of the OTH radars will also benefit.

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